Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/5740--08-9066

Analog Fiber Optic Link with DC – 100 MHz Bandwidth

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May 30, 2008

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-05-2008

2. REPORT TYPE
Memorandum Report

3. DATES COVERED *(From - To)*
June 6, 2006 - October 25, 2006

4. TITLE AND SUBTITLE
Analog Fiber Optic Link with DC – 100 MHz Bandwidth

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
C.A. Sullivan, P.G. Girardi,* and Dieter R. Lohrmann*

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/MR/5740--08-9066

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
One Liberty Center
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
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14. ABSTRACT

An analog fiber optic link covering the frequency range from DC to 100 MHz was designed, constructed, and tested, in order to connect a 10 kA pulse current probe to oscilloscopes for oscillographing laser filament induced arc currents.

15. SUBJECT TERMS
Analog fiber optic link   Wide band
DC

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dieter R. Lohrmann
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UL	17	**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified			(202) 767-0241

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

CONTENTS

Executive Summary

This Fiber Optic link was designed and constructed to connect the 10 kA Pulse Current Probe Laser Measurement Object (LMO) to oscilloscopes for measuring laser filament induced arc currents. Since LMO covers the frequency range from DC to 100 MHz, it was desirable that the Fiber Optic link also cover the same frequency range, including DC. This link was designed and constructed at the Naval Research Laboratory (NRL) because links with these characteristics are not available commercially.

Introduction

This Fiber Optic link was designed and constructed to connect the Pulse Current Probe Laser Measurement Object (LMO) to oscilloscopes. Since LMO covers the frequency range from DC to 100 MHz, it was desirable that the Fiber Optic link also cover the same frequency range, including DC. This link was designed and constructed at the Naval Research Laboratory (NRL) because links with these characteristics are not available commercially. LMO and the link can measure laser filament induced arc pulse currents up to 10 kA.

Fiber optic links are mostly used for digital transmissions. For analog transmissions, the signals are usually first digitized, transmitted over the digital fiber optic link, and then converted back to analog. Links like that are available commercially, but their upper frequency limits are too low if they include DC as the lower limit. Further, these links are quite expensive.

To construct an analog fiber optic link is not trivial because of DC drift of the operating points of the laser diodes. This problem seems to be solved by using two laser diodes in a push-pull configuration, in what used to be called a Class A/B arrangement.

Basic Considerations

In first approximation, the light power that the laser diode transmits is proportional to the DC current applied. This would cause an extremely poor modulation characteristic, if it were not for the fact that the current produced by a receiving diode also is proportional to the laser power received. The transmission characteristic of the laser diode is given by manufacturers in light output power per mA of current, e.g. for the OPTEK OPV315AT the transmission characteristic is 30μW/mA. Similarly, the characteristic of the receiving diode is given in A/W e.g., 0.55 A/W for the OPTEK OPF432 Fiber Optic Receiver Diode. Hence, assuming no loss in the fiber optic transmission line, one mA of current in the laser diode would create 16 μA of current in the receiving diode.

A single laser diode would need to be biased somewhere in the center of its characteristic, causing drift and low stability. This problem was solved by using two laser diodes in a push-pull configuration for the transmitter. Since the diodes have a voltage threshold of about 1.6 V below which no current is flowing, the diodes needed to be forward biased; otherwise, on a received AC signal, there will be a dead time at zero crossovers. It was found experimentally that a forward bias of about 7% of the maximum allowed diode current gave satisfactory results, e.g. the second harmonic being down by 25 dB and the third by 35 dB.

The Transmit Circuit

Figure 1 shows the schematic of the transmit circuit. D3 and D5 are the laser diodes type OPV315AT, manufactured by OPTEK, creating the fiber optic signals. The diodes were matched to give equal performance out of a sample of 25 diodes. Currents of 3 mA and 10 mA were injected into each diode and the resulting current created in a detector diode

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Manuscript approved July 18, 2007.

was recorded. Table 2 shows quite large differences of performance among the diodes. Diodes # 17 and #18 were chosen for constructing the transmitter.

The light output of the laser diodes is transmitted by commercially available fiber optic transmission lines for 62.5 / 125 μm wave length. The connectors are type ST. It was found that this type connector is not quite ideal for analog links, because the amplitude of a transmitted ac signal could vary by up to 20 % when the cable was close to the connector. However, any variations can be calibrated out in this application, as will be explained.

Figure 1 shows the schematic of the transmit circuit. Transistors Q1 and Q2 provide the bias of 2 mA in the laser diodes. The bias is set by adjusting potentiometers R1 and R11 for the voltage across R12 and R13 to read 20mV respectively. For this adjustment, the input terminal is grounded.

The input line is terminated by R6. Resistors R5 and R7 provide an approximate current signal source for the laser diodes. The differential input resistance of the diodes is in the order of 20 - 60 Ω, which is small in comparison to R5 and R7.

The manufacturer of these laser diodes specifies the maximum permissible diode current to be 30 mA / pulse, which means that the maximum peak pulse input voltage at the input terminal is 5V. For CW operation, this should probably be limited to 3V peak.

Capacitors C2 and C3 compensate for the input capacity of the diodes to level the frequency response.

The Receiver

Figure 2 shows the schematic of the receiver circuit. Detector Diodes D1 and D2, OPF432 manufactured by OPTEK, receive the fiber optic signal. They are back biased by +5 and -5 V, respectively. If a fiber optic signal is received, current flows thru the diode to the output terminal J2. The output terminal is loaded by the 50Ω input impedance of the oscilloscope that will be connected to it. The output voltage can be increased by connecting an amplifier with higher input impedance between J2 and the scope, however, this may decrease the bandwidth of the receiver.

Figure 2 also shows the switch that permits remotely turning on the calibration circuit in the transmitter via a third fiber optic link.

Calibration

A 5 MHz calibration signal can be remotely turned on in the transmitter via a third fiber optic link. Figure 3 shows the calibration circuit. Crystal Y1 and transistor Q2 generate the 5 MHz signal, which is amplified by Q3, Q4 and Q9 to provide a sine wave signal with 5.1V P/P into a 50 Ω load. C3, C9 and L2 reduce harmonics of the sine wave signal. Miniature relay K1 switches the calibration signal to the fiber optic transmitter. This allows for switching at frequencies up to 1 GHz. The relay is activated by the fiber optic activation line via fiber optic detector diode D1, OPF432 and Q6. One contact of the relay also turns on the crystal oscillator and amplifier during calibration. Zener diode D3 and transistor Q7 provide a stabilized supply for the crystal oscillator.

The calibration circuit is located in the same enclosure as the fiber optic transmitter. The enclosure also contains two 9 V rechargeable NiCad batteries, which can be charged thru connector P1. The batteries have a charge of 120 mAh. During operation of the fiber optic transmitter the current drain is 18 mA. Therefore, the device can be operated for about 6 hours before recharging becomes necessary. In calibration mode, the battery current drain is 80 mA. Switch S1 on the transmitter enclosure turns on the transmitter. The switch to activate the calibration is located on the receiver box.

The DC shift for no signal input can be calibrated by turning off the arc pulse source with the calibration turned off.

Mechanical

The transmitter is housed in a container which features 0.2" thick aluminum plates for shielding, except for the front panel which is 0.1" thick. The plates are bolted together. The seams are sealed with conductive epoxy in order to shield the transmitter from any external electromagnetic fields. Figure 4 shows the fiber optic transmitter, the receiver, and the fiber optic cable. The circuitry was constructed in a provisional mode; for expediency and proof of concept, no printed circuits were used.

The receiver is housed in a standard sheet metal box.

Test Results

Figure 5 shows the frequency response of the fiber optic link. Because the abscissa is logarithmic, the DC response was not included. Figure 6 shows the input voltage (mV P/P) vs. output voltage (mV P/P) for a sine wave with a frequency of 10 MHz.

The 5 MHz calibration signal creates 106 mV P/P at the output loaded with 50Ω, i.e., -15.5 dBm. The harmonic levels were

Frequency (MHZ)	5	10	15	20	25
Level (dB)	-15.5	-40	-52	-55	-65

Table 1 Harmonic Levels

Figure 7 shows the DC shift measured as a function of the input sine wave voltage P/P. Figure 8 shows the DC characteristics of the link. The performance can be linearized by processing the received signals and then using software that corrects for deviation from linearity.

DIODE #	Output Current for 3 mA input (μA)	Output Current for 10 mA input (μA)
1	60	576
2	56	486
3	90	640
4	92	374
5	52	538
6	40	556
7	58	548
8	30	310
9	60	508
10	44	322
11	74	372
12	62	544
13	40	510
14	12	114
15	66	332
16	80	652
17	86	720
18	88	730
19	56	468
20	74	600
21	60	514
22	58	608
23	16	114
24	142	822

TABLE 2: Characteristics of Diodes

3 dB Bandwidth	DC to 100 MHz
Max. Input Voltage	± 3 V into 50 Ω
Gain	-33 dB
Harmonics	< -25 dB
Noise Figure	< 10 dB
Dynamic Range	78 dB

TABLE 3: Summary of Performance

Figures

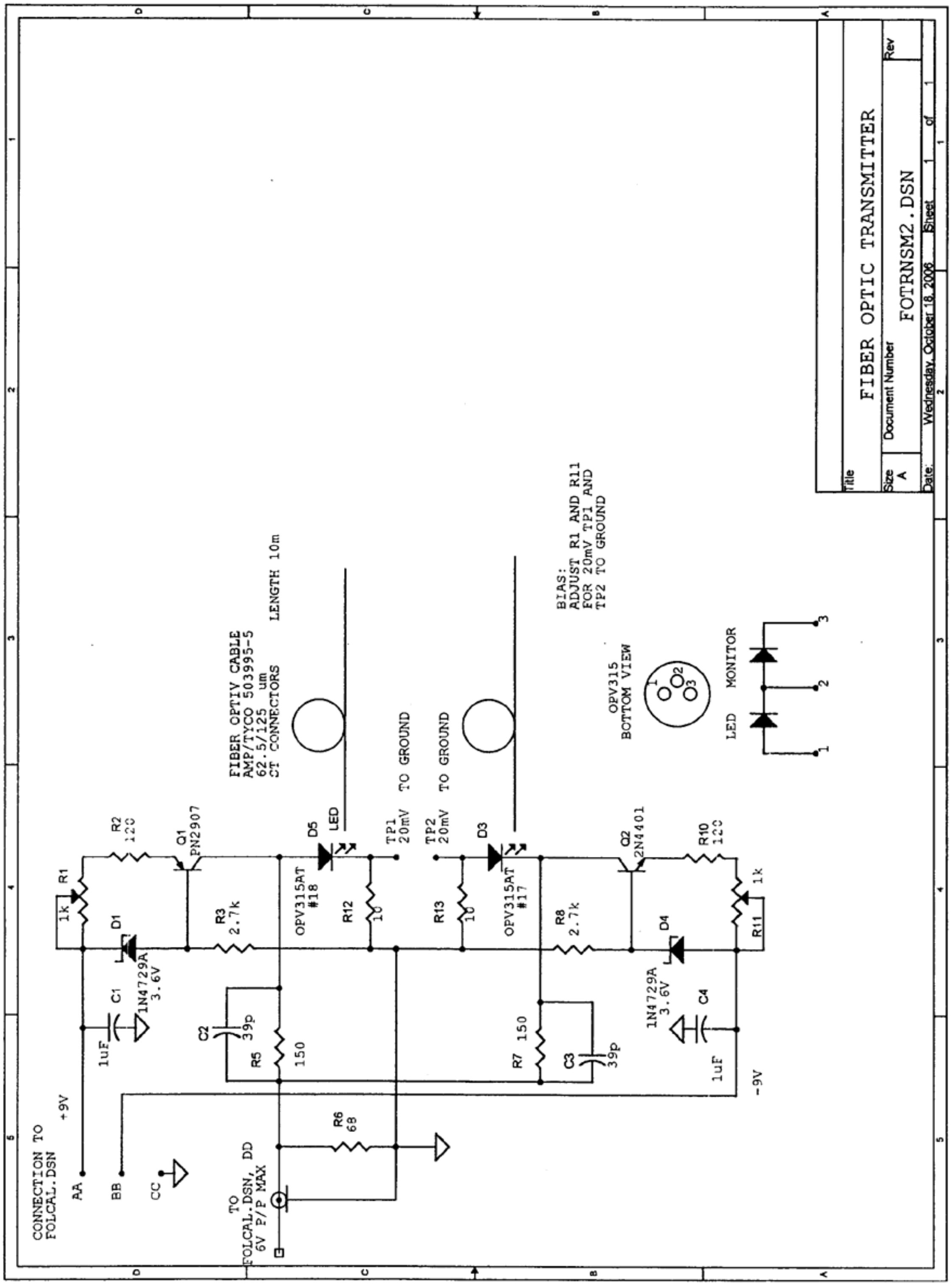

Figure 1: Fiber Optic Transmitter

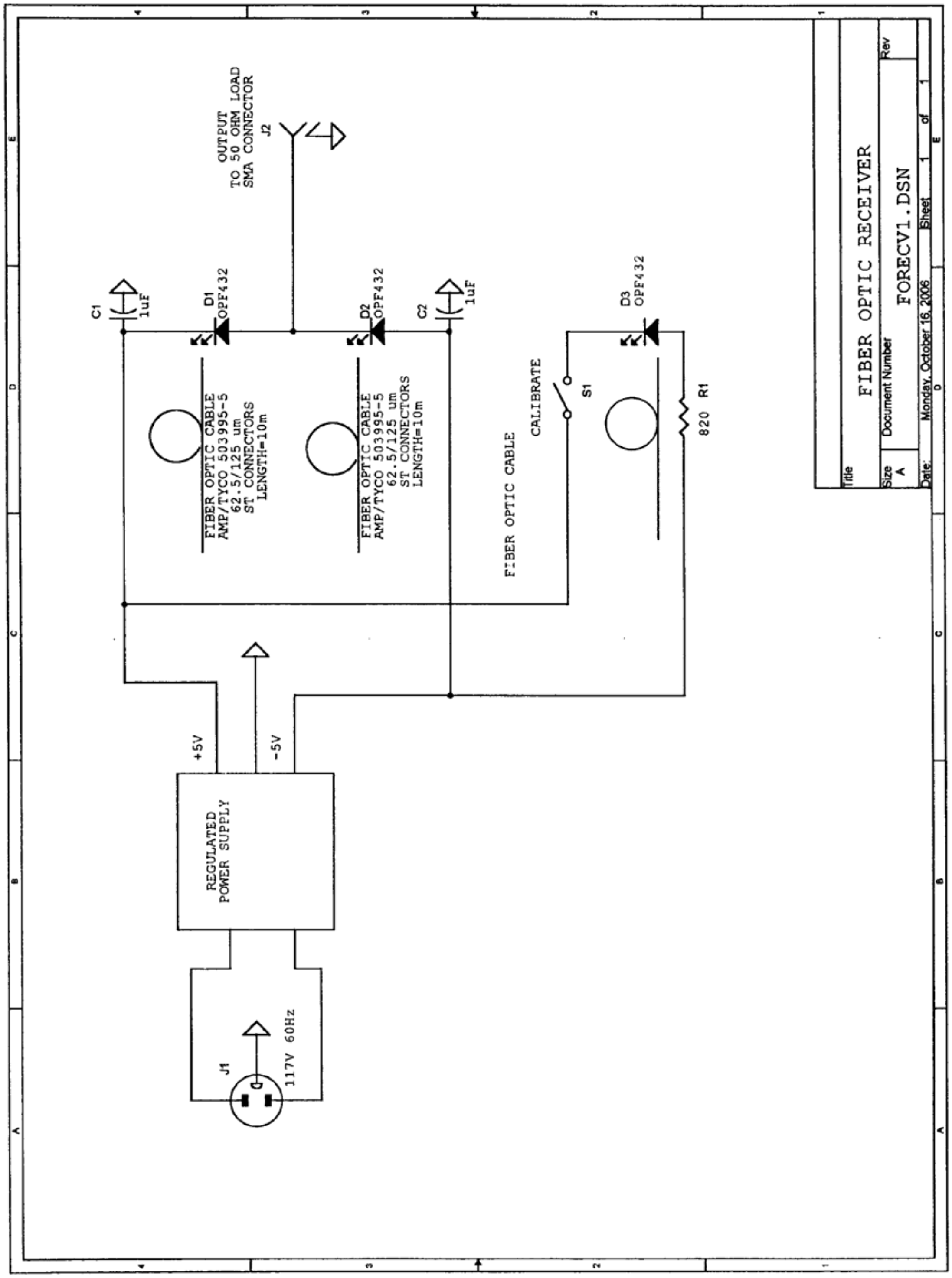

Figure 2: Fiber Optic Receiver

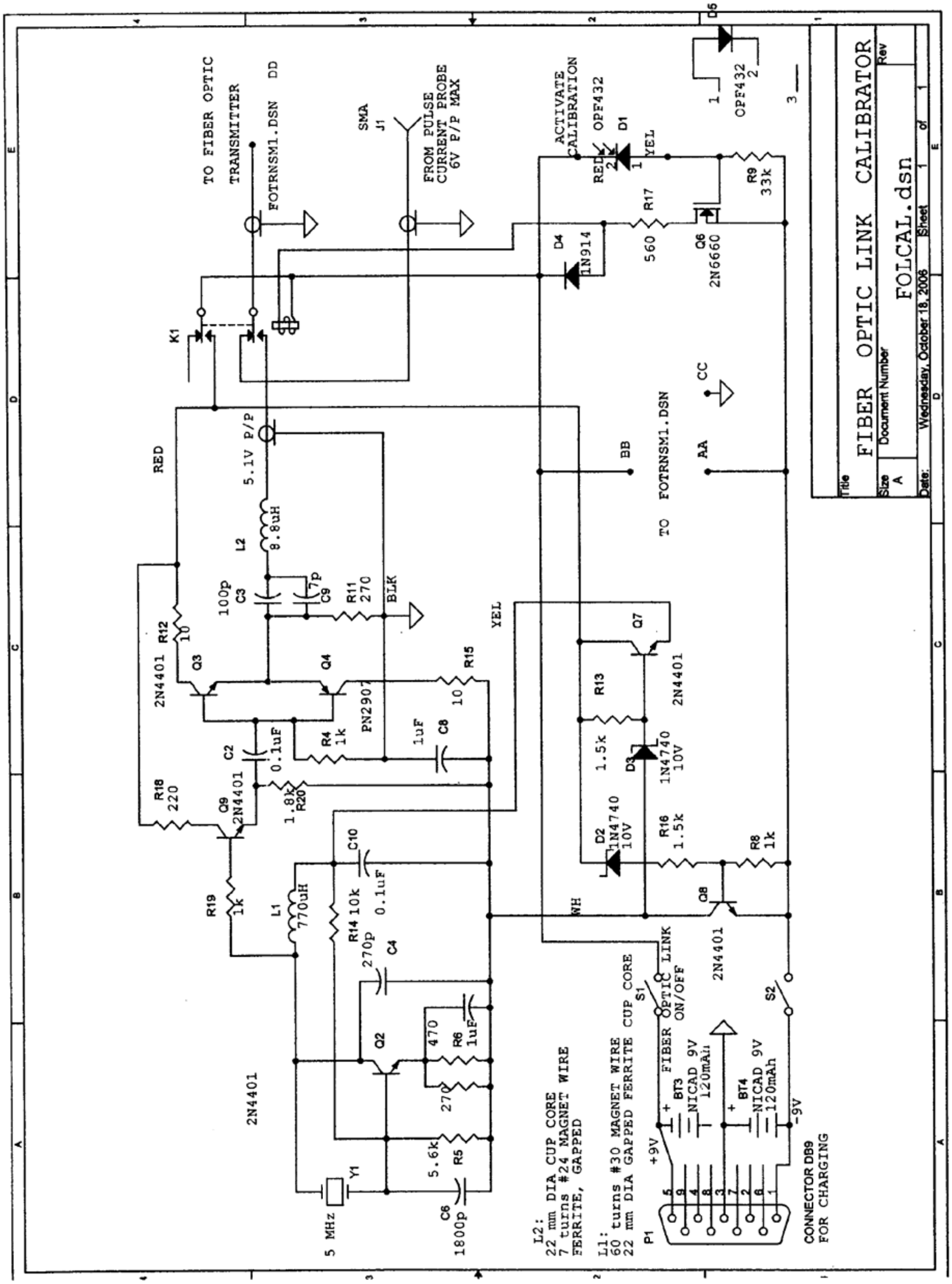

Figure 3: Calibration Circuit

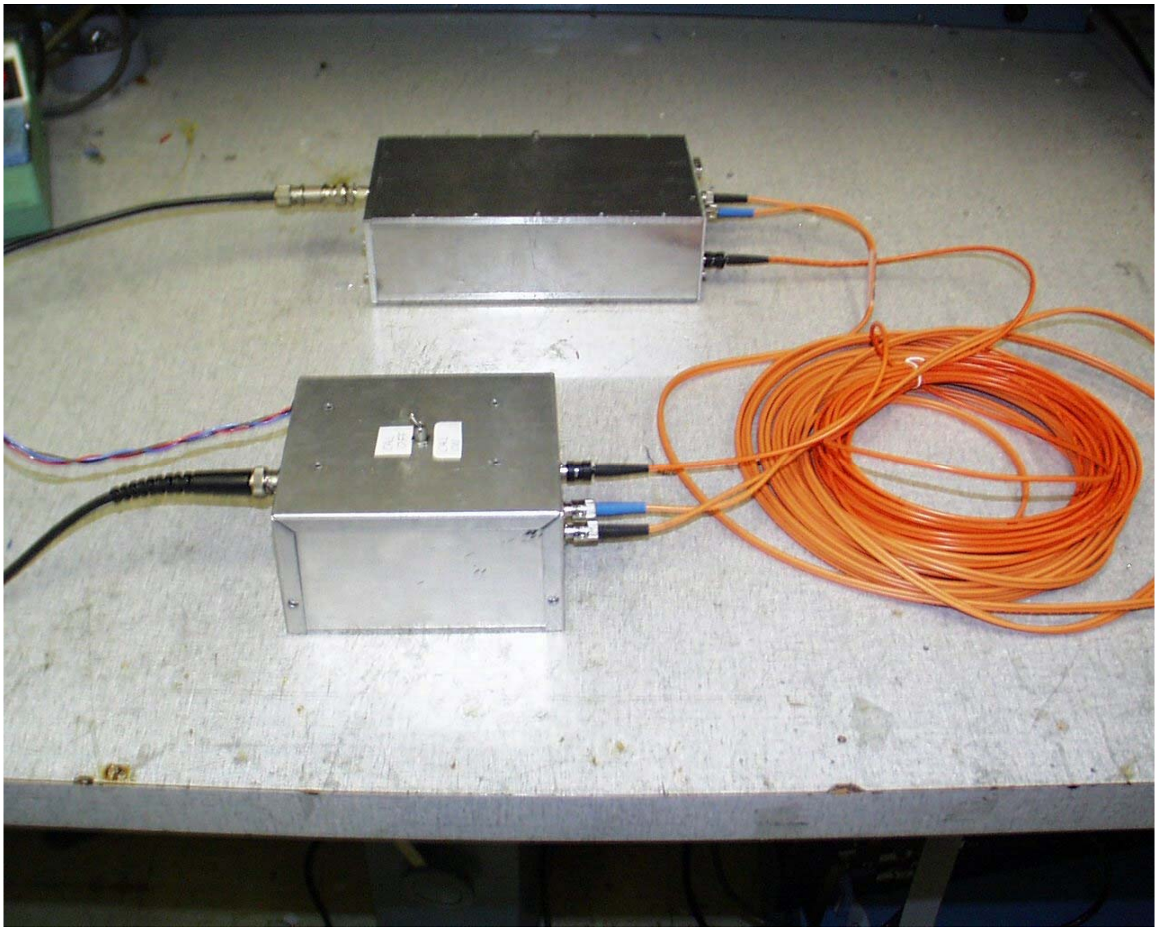

Figure 4: Fiber Optic Link

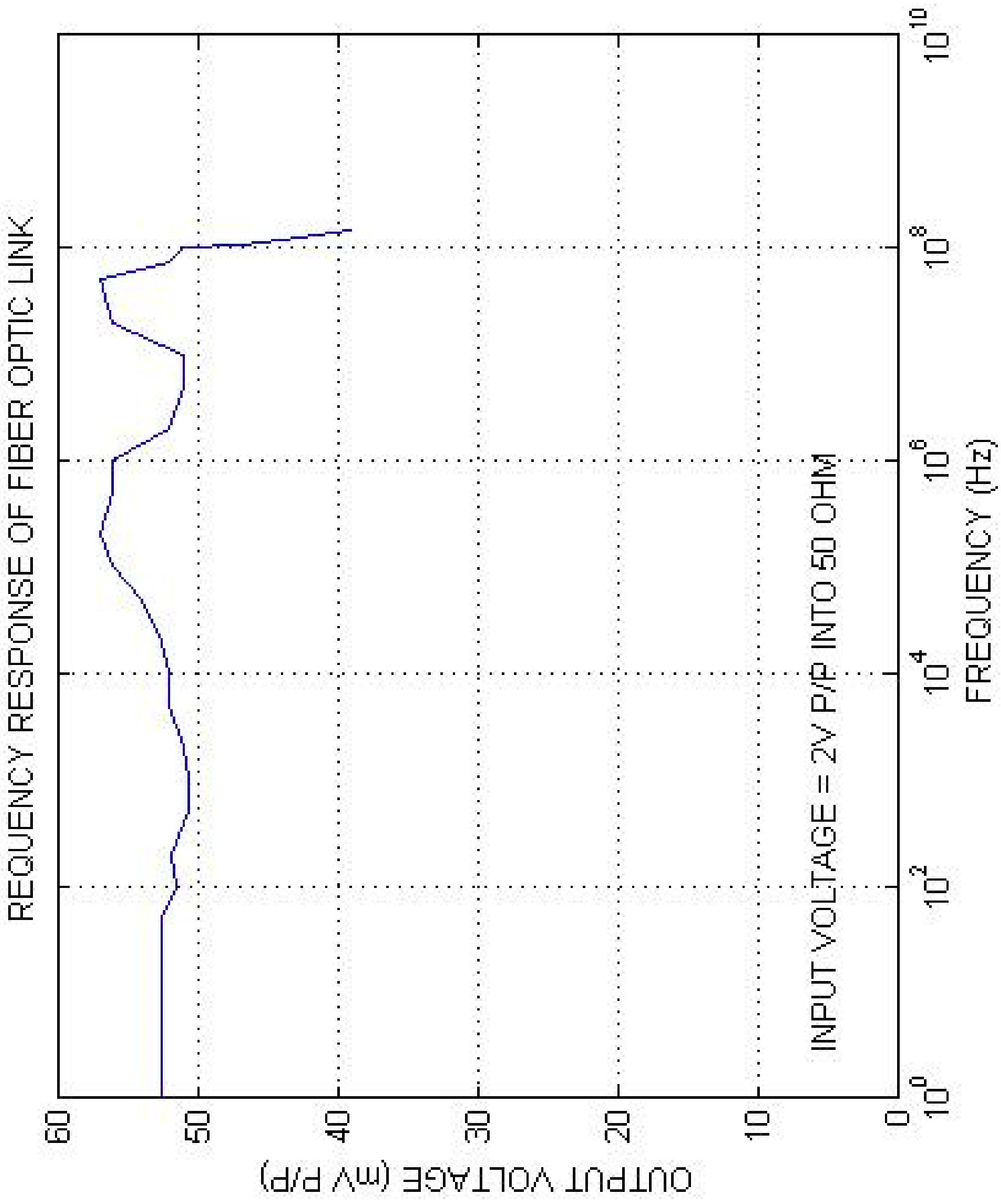

Figure 5: Frequency Response of Fiber Optic Link

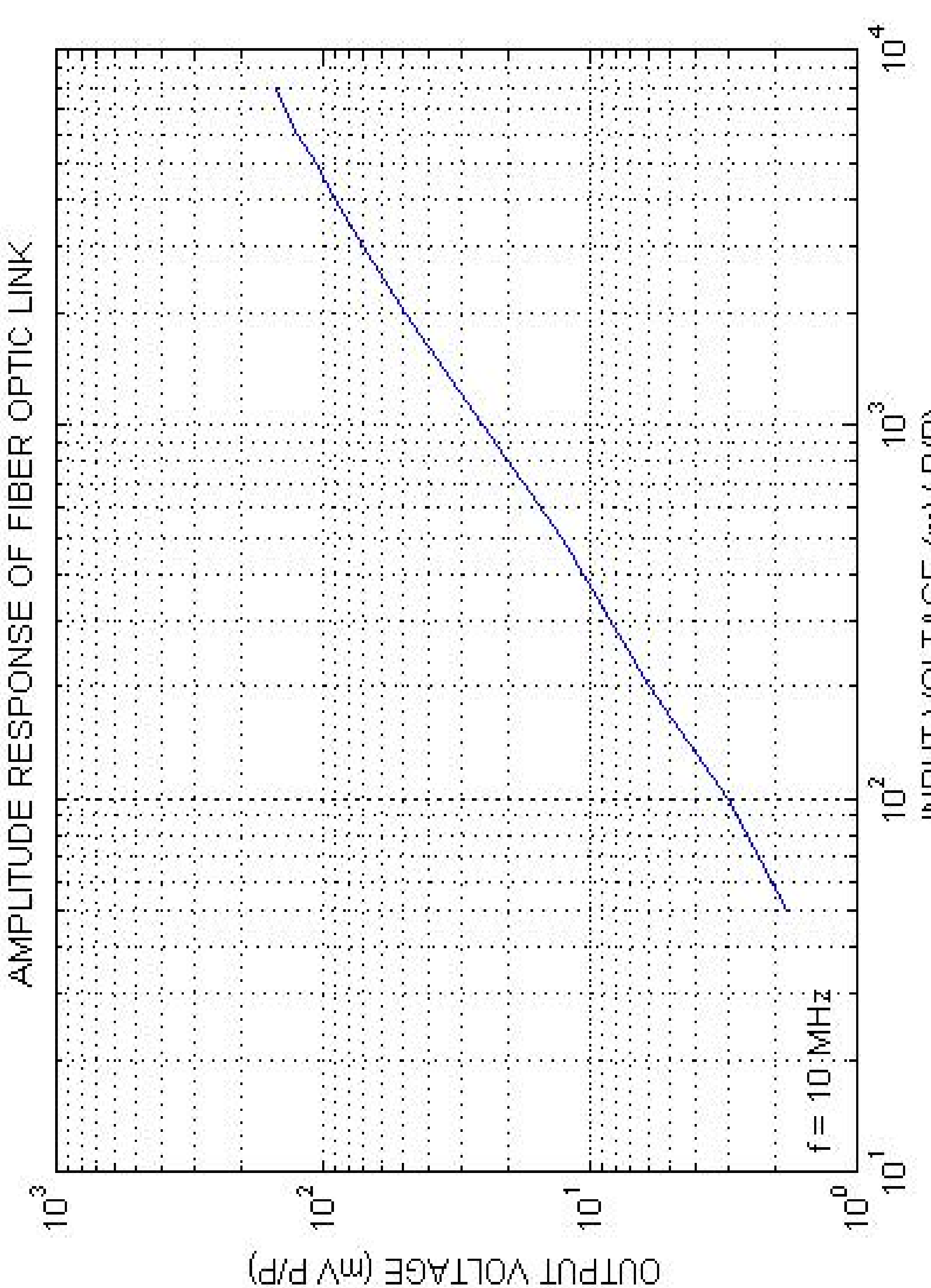

Figure 6: Amplitude Response of Fiber Optic Link

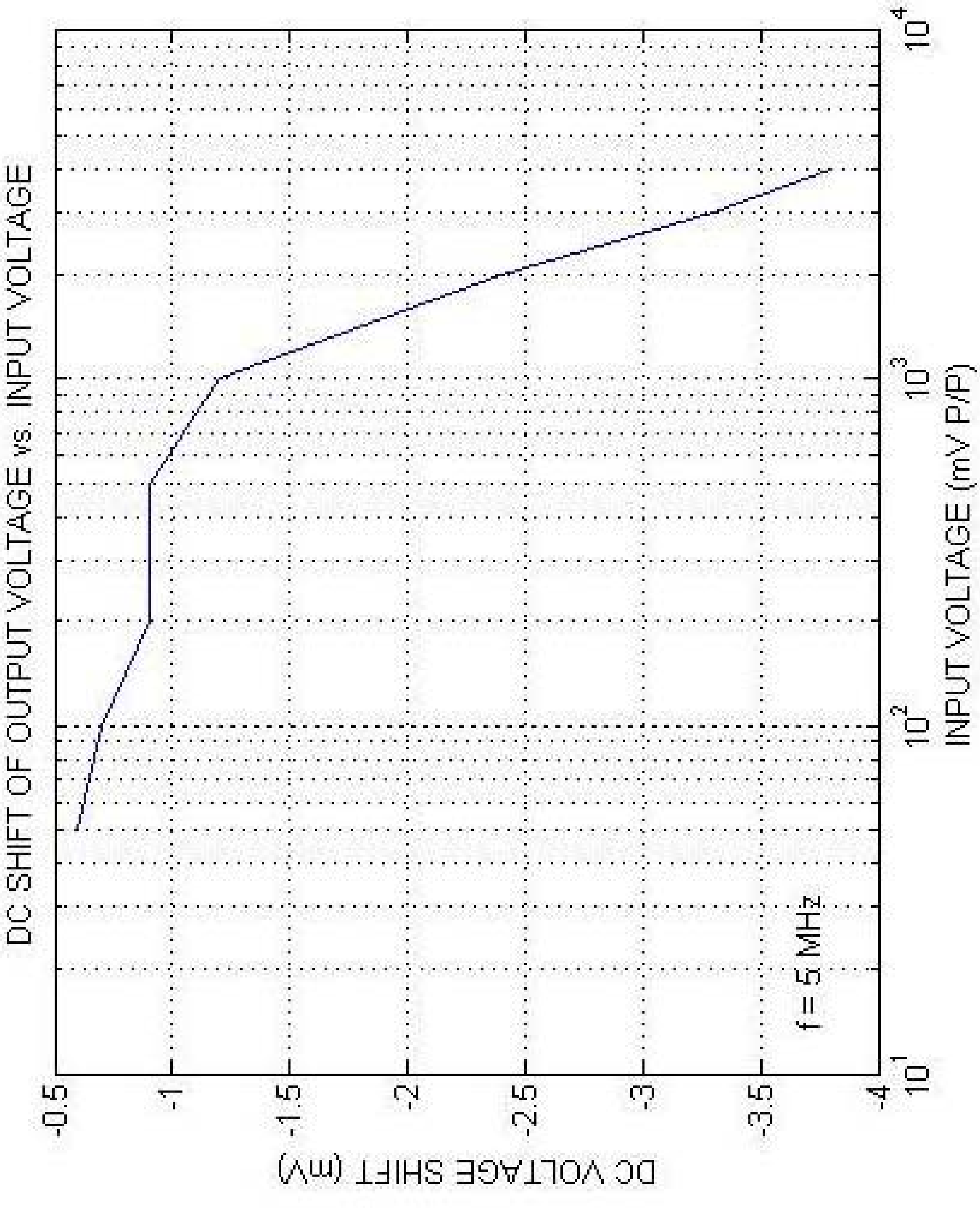

Figure 7: DC Shift of Output Voltage vs. Input Voltage

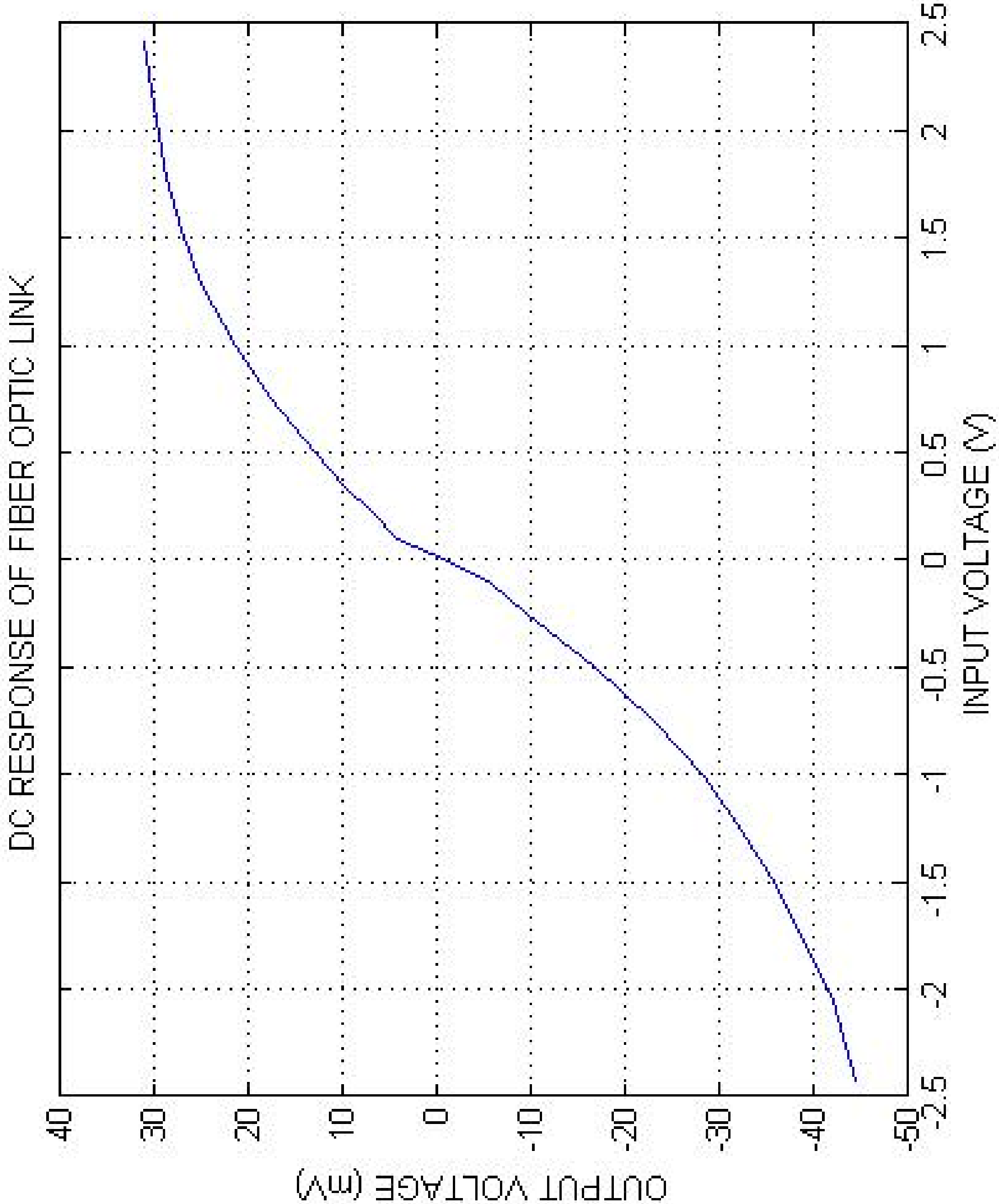

Figure 8: DC Response of Fiber Optic Link